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Abstract

The classroom environment is a working surround in which children, through participating in organized experiences, can grow and develop in an optimum manner. Classroom design requires organization of principles of environmental control in order to assure efficient and successful performance. This control cannot be left to chance. In considering the nature of the human organism, how it regulates and maintains its body temperature, as well as those changes which occur under various forms of activity, three factors are relevant to design and control of the thermal environment of classrooms--(1) the developing child differs from the adult and needs a different set of standards for controlling his thermal environment in the school, (2) thermally induced stresses can alter the growth, development, and learning of children, and (3) the child's problem-solving capacity is affected by the effective temperature of his classroom. If we are to meet the needs of our growing children, then this understanding necessary for proper classroom design must include knowledge of the control of heat, air movement, and humidity along with that of light, sound, structural materials, teaching space, and the other areas that enter into making adequate classrooms in our schools. (Footnote references are given). (KK)

ED033531

CONTROLLING

THE THERMAL ENVIRONMENT

of the

CO-ORDINATED CLASSROOM

DARELL BOYD HARMON

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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Foreword

There have been several earlier investigations into the relation between learning and the thermal environment, but all of these have been somewhat limited in scope, relating singularly to health, comfort or other isolated aspects.

This work is an attempt on the part of Dr. Harmon to take into consideration the full impact of the thermal environment on the whole child as it relates to his learning.

With this in mind, publication of this monograph has been done as an educational service by Honeywell.

Minneapolis-Honeywell Regulator Company
JOHN E. HAINES, VICE-PRESIDENT

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CONTROLLING THE THERMAL ENVIRONMENT OF THE CO-ORDINATED CLASSROOM

1. *Introduction*

"The child is inseparable from his environment" has become virtually the first axiom of child development. The realization of the organic child's potentialities for growth, development, and well-being, and what he ultimately does with the capacities he brings into this world are largely determined by the surroundings in which he is placed. From the physical point of view his surroundings mean the purposeful and the chance organizations of energies (i.e., heat, light, and sound) and the physical restraints (i.e., furniture, books, tasks, etc.) he meets in his day-to-day environment.

Because of the time and intensity factors involved in the tasks required by the school, and the major place the school now occupies in determining the future of the child in this complex civilization, the energy organizations and physical limits of the classroom are probably the most significant of all those he encounters in shaping the child into his ultimate social form. For optimum learning and development the classroom designer must bring the control of the significant energy organizations of the classroom into a pattern more nearly in keeping with a possible realization of the full potentialities of children during the school phases of their development.

The energies of biological significance in the classroom fall into two equally-important categories: those that induce communication and action (such as light and sound), and, those that determine task rapport and the metabolic processes which make purposeful action possible. In this second category are the energy aspects of the thermal environment.

In their impact upon the organic child, in their definitive influence upon the child's capacities to grow, develop, and learn, these two energy categories are of equal importance. But classroom design in the visual and auditory areas has been profiting greatly from intensive research and enlightened application, while the highly-important aspects of the child's thermal environment are too often obscured by failure to recognize the part that environment plays in learning.

Because of the long-time emphasis in education on communication through speech and the printed word (and approximately 80% of the instruction in school is by visual means or through spoken words interpreting visual experience), research in

vision and the control of light, and in audition and the control of sound, has advanced far in relation to our understanding of children and the learning process. This research has brought with it comparable advances in the application of derived principles to design of classrooms.

Compared to our knowledge of light and sound, very little is generally known about the energy aspects of the thermal environment as it affects learning rapport and learning performance. In spite of education's increasing emphasis on the principle that "the child learns through activity" the thermal determinants of that activity have received little consideration in learning investigation. As a consequence, while school plant design for controlling lighting and sound have been forging spectacularly ahead, the control of classroom heating and ventilation have seen a minimum of change and improvement.

In the light of education's increasing understanding of the organic aspects of learning in activity curricula, heating and ventilating standards which seemed forward-looking in the period between 1930 and 1945—the period of their most recent and aggressive construction and elaboration through research—now reveal many basic inadequacies. These standards are largely concerned with keeping the child "warm" and "comfortable," with the underlying concepts of "warmth" and "comfort" derived from data secured by studying resting adults, and the underlying concepts of education taken from the formal, regimented, "pouring in" programs of the schools of yesterday which looked upon learning as a "passive absorption" process.

Among other factors, the mass-skin ratio of the child is different from that of the adult, so the child's needs in balancing his internal heat with that of the environment is different. Adult standards for the thermal environment cannot be assumed to be adequate for the child in school. In addition, in modern activity programs, the child's heat production varies with the activity. The child in school needs not a fixed, but a flexible controlled thermal environment to meet his learning needs. Then, too. research is indicating problem-solving rapport (the basis of successful learning-by-doing programs) comes from maintaining a uniform level of retained body heat. If internal body temperatures go above or below certain levels, children cannot learn well, respond well, or even maintain satisfactory rapport with their educational experiences. The maintenance of a uniform level of retained body heat satisfactory for full learning and development through all the activities of modern curricula is much more complex than merely providing heat at a certain level sufficient to produce a subjective feeling of "comfort." All aspects of effective temperature must be controlled within the limits required for active, learning, growing, developing children.

A working concept of the biological and physical side of learning is first necessary if we are to construct a systematic approach to meeting the school child's thermal needs.

2. *The Co-ordinated Classroom*

The classroom environment is a working surround in which children, through participating in organized experiences, can grow and develop in an optimum manner, and channel their unfolding capacities into constructive and satisfying living. Like all occupational environments, classroom design requires a systematic organization of principles of environmental control, in order to protect those who work in it, and to assure the efficient and successful performance of the task they do.

The hypotheses basic to the Co-ordinated Classroom* are of profound significance in the growth, development, and well-being of the organic child in school. A review of these hypotheses will show in a general way the decisive and determinative role played by the thermal environment of the school child, when considered with the other energy organizations and restraints inherent in his surround.

The child's principal job is to grow and develop; to master and direct all of his potentialities in a manner that he may become a satisfied and efficient member of society. His books, his studies, his multitudinous educational experiences—even his organized play—are all parts of this most important of jobs.

The classroom environment is an *occupational environment*—a working surround in which children, through participating in organized experiences and performing selected and directed tasks, will grow and develop in an optimum manner; master their resources; and channel their unfolding capacities into constructive and satisfying living. Like all occupational environments, which restrict the free and undirected activity of the individual, the classroom environment requires a systematic organization of principles and techniques of occupational hygiene for its control in order to protect those who work in it and to assure the efficient and successful performance of the tasks they do. These principles and techniques of occupational hygiene and environmental control must be derived from the psychological and physiological nature of the workers in that environment (the growing and developing children), the kind and purpose of the tasks they are to perform (the curriculum), and, the manner in which those workers master and perform those tasks with greatest efficiency (the physiology, psychology, and psycho-physics of learning).

Before setting up some principles of environmental control for the classroom, some commonly neglected principles governing the organic child should be examined.

1. "The human organism strives to grow, develop, and function as an integrated whole.
2. "Within certain limits, the human body is an organic mechanism fitted to survive by its capacity to adjust itself or its relationships to the environment in which it finds itself . . . to go into action to establish balances with the forces and restraints which surround it, such as gravity, light, sound, heat, and the like.

*Darrell Boyd Harmon, "The Co-ordinated Classroom," published by American Seating Company, Grand Rapids, Michigan, 1949.

The organism accomplishes this by shifting its internal equilibria between various bodily systems and parts, and by modifying or adapting many of its structures, through repeated function to fit the specific environmental factors which it encounters in its day to day existence.

3. "The organism's adjustments and adaptations, however, are not made merely to the socially purposeful portions of the energy distributions of light, sound, and the like, as they are represented by the teaching materials in a planned learning situation. The organism seeks to adjust and adapt not only to these stimulating forces, as they are presented in its "educational experiences," but it also seeks to adjust and adapt to the total distributions of all forces and restraints surrounding it which are in its sensory range.
4. "Organically a child adjusts and adapts to the total pattern of energy distributions which sets the human organism into action.
5. "Psychologically and socially, the child adjusts to the socially or emotionally defined meanings attributed to certain portions or limited organizations of those energy distributions."

The concept of the "Co-ordinated Classroom" was formulated to bring the control of the significant energy organizations and physical limits of the classroom into a pattern more nearly in keeping with a possible realization of the full potentialities of children during the school phases of their development. This concept is based on five assumptions (among others) derived from well-substantiated data existing in the standard research literature on the energetics of human behavior. These assumptions are:

1. The human organism is a homeostatic mechanism, i. e., all behavior is an attempt to preserve organismic integrity by homeostatic restoration of equilibrium, as that equilibrium is disturbed by biologically significant organizations of energies in the external or internal environments of the organism;
2. These homeostatic action patterns proceed towards maintenance of equilibrium (or of the relationships between organism and stimulating energies) with "least effort";
3. Specific sustained stress, or repeated, or continued overt or covert action of the organism alters the structure or function of parts or systems of the organism so that it can more readily, or more economically resolve similar stress, or proceed towards equilibrium when stimulated to similar activity;
4. All psychological phenomena have overt or covert motor accompaniments that are a necessary condition of those phenomena; and,
5. "Learning" is derived from the alterations of physical structure or function, within the tolerances of the organism, which accompany the sensorimotor actions set up to reduce stresses induced by certain socially-defined organizations, or

portions of organizations, of the energies of the surround (i. e., the brightness contrast of type with paper, etc.).

These assumptions have significant corollaries for the design of classrooms:

1. The densities and gradients of the biologically significant energies in the classroom must be such that the stresses they induce and the actions they arouse can be resolved with least effort to prevent alterations of structure, or function, which might be handicapping to the organism;
2. The densities and gradients of those energies also must be such that the alterations in structure and function they produce in the child will have constructive outcomes in promoting the efficiencies of his subsequent growth, development, and learning; and,
3. The energies of the classroom environment must be organized to promote optimum rapport with, and full freedom of performance towards, the purposeful stimuli of the learning task.

The "Co-ordinated Classroom" concept is particularly concerned with the control of the physical aspects of the energy, task and space factors of the classroom so as to meet the physiological and psycho-physical needs of the school child. In the "Co-ordinated Classroom" environment:

1. Light (both natural and artificial), heat, sound, and other biologically significant energies are distributed and maintained on coincidental, three-dimensional, rectilinear co-ordinates (the Y-axes of which are co-incident with the principal line of gravity for each child) at as nearly uniform densities as are necessary to meet physiological tolerances;
2. Structural and space factors (such as energy sources, light reflectances, color, heat, humidity, air movement, density of surface materials, and the like) which could alter or interfere with optimum psycho-physical and physiological efficiency in task performance are rigidly controlled so as to keep them within the tolerances determined both by the task and by the physiological and psychological requirements of growing and developing children; and,
3. Equipment, such as desks, seats, etc., is designed not only to provide adequate body support with gravity, and with the task to be performed, but also to support and promote the dynamic body mechanics entering into the task performance.

These considerations lead us to the Co-ordinated Classroom as the work environment most patently conducive to optimum maturation, development, and functioning of the total child. To ignore so paramount a factor of that work environment as its thermal aspects is to delimit the contributions, however enlightened, of its other physical factors.

With this in mind, let us reassay the factors pertinent to the organic child's requirements for his thermal environment.

3. *Criteria for Thermal Control of the Classroom Environment*

Thermal environment standards in the classroom must be based on the efficiently-functioning child. He is solving new problems, meeting new challenges, learning through activity. Measurements of resting "comfort" are subjective and diffuse. If we set effective temperature standards objectively so as to promote the organic child's readiness and efficiency to perform, comfort will be a dividend of that readiness and efficiency.

Before we can establish criteria for thermal control in the classroom we must first clarify some misconceptions which have grown up around the objectives of thermal control in the child's working environment. To do this we must see the organic child for what he actually is. We must assess his classroom thermal environment in terms of what it must, in actuality, contribute to the child's growth, development, and well-being. And, we must re-evaluate some commonly accepted meanings of "effective temperature" in terms of the learning child, and determine the proper role of "effective temperature" in the organic child's educational experiences.

In the "Heating, Ventilating, Air Conditioning Guide, 1952," the American Society of Heating and Ventilating Engineers tell us:

"Sensations of warmth and cold depend not only on the temperature of the surrounding air as registered by a dry-bulb thermometer, but also on the temperature indicated by a wet-bulb thermometer, upon air movement, and upon radiation effects. Dry air at a relatively high temperature may feel cooler than air of lower temperature with a high moisture content. Air motion makes any moderate condition feel cooler. Radiation to cold or from warm surfaces is another important factor under certain conditions affecting the comfort reaction of the individual.

"Combinations of temperature, humidity, and air movement which induce the same feeling of warmth are called thermo-equivalent conditions. A series of studies at the A. S. H. V. E. Research Laboratory established the equivalent conditions for practical use. This scale of equivalent conditions not only indicates the sensation of warmth, but also to a considerable degree determines the physiological effects on the body induced by heat or cold. For this reason it is called the *effective temperature* scale or index, and it denotes sensory heat level.

"*Effective Temperature* is an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement. It was determined by trained subjects who compared the relative warmth of various air conditions in two adjoining conditioned rooms by passing back and forth from one room to another.

". . . effective temperature is an index of the degree of warmth experienced by the body. An effective temperature line is, therefore, a line defining the various

combinations of conditions which will induce like sensations of warmth. . . ."

In other words, an "effective temperature" scale is established by first finding a basic combination of heat, humidity, and air movement in which resting adults will feel "comfortable," that is, in which they will be able, physiologically:

a. to balance body heat output with the input from the surroundings without change of body functioning; or,
b. to dissipate into the surroundings any excessive body heat over that necessary to maintain an optimum body temperature for efficient physiological functioning in the activity in which they are engaged (resting); or,
c. to maintain their functional and feeling tone status quo, without being stimulated by internal or external temperature conditions to alter that functioning.

Such an approach to determining standards for the thermal environment takes into account all the physiological processes by which the organism adjusts its body heat in relation to all the physical factors of the thermal surround. When this basic combination is found, because of physiological tolerances a range of effective temperatures is next determined in which there is apparently no alteration in comfort, or the functioning of the individuals on which the scale is being standardized (i.e., the spread for summer comfort of 69 to 73 ET.) When this is done, other comparable combinations of heat, humidity, and air movement are determined subjectively by the method of comparison indicated above.

In any case, the thermal values set up are based on a combination of dry bulb temperature, wet bulb temperature, and air movement rate, as that combination serves to support the body heat or metabolic aspects of maintaining the functioning in which the organism is engaged. These values or standards are not derived from a single thermal environment factor, such as dry bulb temperature, as much of the design practice in schools would indicate is popularly assumed.

Of necessity, thermal standards must be based on or determined by tests of individuals engaged in a minimum of activity, preferably resting. The rate of body heat output varies with various tasks or activities. Individuals approach a common and comparable level of heat output only as their activities are minimized, hence, the use of "resting comfort" as a base for establishing standards for the thermal environment. However, these base standards cannot be used indiscriminately in setting thermal values for a working environment. They must be readjusted to take into account at least the average body heat output in the tasks being performed in that environment.

The child in school is a functioning child, a doing child, an organism at work. Comfort is a "composite sensation derived from a feeling of warmth which is related to the skin temperature, a sense of freshness which depends on a lack of congestion in the upper respiratory mucous membrane, and nerve impulses produced by light, fluctuating air movements on the skin."[1] Comfort is defined as "contended enjoyment."[2] To be "comfortable" is to be "content," to be "at ease," to be "free from pain or

distress." The connotative overtones of comfort are therefore, passive, negative, static. Standards based on "comfort" can too easily imply the assumption that the child's reason for awareness of his thermal environment is only to maintain a contact with that environment so he can know when it is necessary to move to a place where he can be at greater "ease." While the nature of effective learning is such that actions should lead towards the reduction of tension or the maintenance of an activity or balance with "least effort," this "least effort" cannot and should not be interpreted as something static, or the child at rest. "Least effort" in a learning sense implies minimum inertia, least expenditure of energy or use of body equipment, for optimum efficiency of performance.

Heating, ventilating, and air-conditioning specialists tell us that "the comfort zone is very similar to the zone of thermal neutrality."[3] And the zone of thermal neutrality has as its median "a neutral point" at which "the individual is fasting and at rest, and has to take no particular action to maintain its body balance."[4]

Thus we see that comfort standards taken without thought could be conducive to producing a static child or a child at rest or at ease. This is not the child in school, for the "passive absorption" methodology in school has been long since abandoned as invalid. The child finds things out for himself, under the teacher's guidance, by "digging and doing." Therefore, our criterion is not the child with his "motor idling," it is the "problem-solving" child. Our ambition is not the statically comfortable child, but the efficiently-functioning child. We must strive toward a thermal environment which will motivate the "doing" child, the "problem-solving" child, rather than one which will put the child into a "neutral" state.

We see, therefore, that "comfort" is not our primary objective in defining the optimum thermal environment of the classroom. It would not be, even if we were capable of evaluating "comfort" with any degree of specificity or precision. But we are not.

These same heating, ventilating, and air-conditioning experts tell us that "there is no precise physiological observation by which comfort can be evaluated."[5]

Measurements of comfort are subjective and diffuse. They take for their point of departure a number of externals which are mutually variable. Comfort standards set up to measure any environment of necessity have inherent in them qualifications reminiscent of the laboratory in which they were formulated. They are not adequate or dependable standards for assessing the school child's thermal needs, for we must always ask, "Where did you measure and under what conditions? Whose comfort was measured? Is the situation at issue here equivalent to the task the individual was performing in that set of circumstances?"

In addition, "comfort" standards are much more difficult to determine for children than adults. The child is less critically aware of his thermal comfort than the adult in the sense that thermal inequities will evoke from him far less conscious notice and overt complaint. Within limits, overheating or chilling will find him

relatively heedless. On the other hand, his motor responses are much more immediate and marked. Though his attention is not focused upon his sensation of discomfort, we will find the cold child moving about, squirming, wiggling, flexing his muscles, activating against heat loss. The overheated child gradually drifts into a state of comparative lethargy and passivity long before he is aware that he is uncomfortable. In short, since he is more easily satisfied with any given thermal environment, the child's idea of his own comfort is unreliable for precise measurement.

To aim at comfort in our efforts to define the most effective thermal environment for the child in school is, therefore, to "shoot at a moving target." Significantly, also, it is to ignore the basic contributive essentials in that environment.

Thermal environment standards for the classroom must be based on the "efficiently-functioning" child. He is solving new problems, meeting new challenges, learning through activity. As an active growing organism, he functions most effectively as he goes toward the continuance of task with the least stress, the least tension, the least restraint. Stresses, tensions, restraints diminish as the organism moves into optimum rapport with its environment.

If we set effective temperature standards for the child's thermal environment with his heightened efficiency (as a problem solver) in view, we will arrive at his "comfort" along the way. If we determine values for controlling dry and wet bulb temperatures and air movement rates so that the child in any educational task can proceed toward least effort, can adapt without damaging structure, comfort becomes not an end, but a by-product. The organic child's readiness and efficiency to perform at an optimum level is our aim. His comfort is simply a dividend of that readiness and efficiency.

For the dynamic implications of the child's thermal environment, we must look first at the nature of the organic child.

4. *The Nature of the Human Organism*

Man owes his superior position among organic forms largely to the variability of adjustive behaviors permitted by his structures. Despite man's splendid adaptability, it must not be assumed that he can ignore nature's laws and still preserve the efficiencies or the well-being of his various structures which contribute to his adaptation. The provision of the energies of action, the maintenance of readiness to act, and the facilitation of appropriate activity—the metabolic and thermal aspects of human performance—are of major significance in successful learning and in the ultimate well-being and the efficiency of the individual.

The organic child is a "growing action system"[6] in the "patterning process of becoming a mature organism." Specialists in child development have found that he has "at once a unique pattern of growth and a generic pattern which is characteristic of the species to which he belongs."[7] Any understanding of the child in relation to the environment in which this growth and patterning takes place must take into account the general characteristics of the human organism as a whole, and the particular characteristics and variations which are peculiar to the child as an immature representative of the species.

Let us look first at the general characteristics of the organism. Man is a biochemical organism, a living energy system,* subject to all the actions and limits of his biological and chemical heritage. We live in a world composed of energy systems, each dependent for its form and function upon the interactions of various energy organizations, or, upon transforming energy from one form to another.

Nature is an experimenter. Out of that basic constituent of the universe, energy, she has devised two types of structure—inorganic, and living matter. Each of these represent organizations of certain energies within the whole into energy systems that make for form and substance. Both are so organized, according to the fundamental laws governing energy, that their units operate towards the preservation of their integrity through certain mechanisms or patterns of maintaining internal and external equilibria. Both are limited in this function by those basic laws governing their organization, and both are subject to destruction or distortion when meeting external forces greater than the forces which maintain their integrity.

Inorganic matter represents nature's effort to organize energy into apparently stable substance—if not closed or static energy systems. Its primary forms are comparatively fixed, and their capacity to maintain integrity within the forces which surround them is dependent upon the stability of their internal forces. The perpetuation of the integrity of inorganic structures and the adjustment of their relationships with external forces and forms, depend entirely upon the nature and extent of external factors.

*Freeman, in the ENERGETICS OF HUMAN BEHAVIOR, defines "energy system" as "an arrangement of work capacities, potential or aroused, which forms a unified whole."

Living matter, on the other hand, represents nature's effort to create structure by organizing energy into open, or dynamic energy systems. Its forms are variable. Their capacity to maintain integrity within the forces which surround them is derived from capacities to adjust their internal equilibria, to utilize external energies or forms to alter their own equilibria or form, and to change relationships with external forces and forms so as to establish new balances with them.

These capacities for promoting integrity and adjusting equilibria are inherent in the way dynamic energy systems are organized to form the basic substance of living matter, protoplasm. Biologically, as distinguished from the physical or chemical actions on which they are based, these capacities can be classified as follows:

1. *Irritability*, or the capacity to change physical relationship with external forces or form;
2. *Metabolism*, or the capacity to assimilate external energies or forms in modifying or repairing structures, or restoring internal energy balances; and, to reject those energies or substances which do not promote the structures total economy; and,
3. *Reproduction*, or the capacity of living matter to create from its own energies or substances similar dynamic energy systems or structures.

In general, these capacities of protoplasm are expressed in two major functions of the structures of living organisms. One of these major functions is realized through the operation of structures and systems within the whole organism by which situations of significance arising in the external or internal milieu of the organism are detected, appraised, and appropriate actions or adjustments of the organism are instigated to solve its relation with those situations. These operations are represented by those of the various sensory-motor and other communicative systems of the body, and their supporting structures, together with the integrating, scanning, computing, and servo-mechanic actions of the brain and its related mechanisms. These operations are largely biophysical in nature.

The second of these major functions is achieved through the operation of those bodily processes and systems that have to do with structuring and maintaining body parts; providing the energies for their functioning; keeping body parts in a state of "readiness" to function; and, expediting or facilitating their functioning, when needed, by overcoming certain inertias or accelerations which could interfere with their mobilization or functioning at the proper time or in the proper sequence. These operations are largely biochemical in nature, and as will be seen later, they have a significant thermal component.

Within the two types of organized energy systems which make for form, nature has created many physical substances and grosser structures. Basic to each of these, however, are the fundamental laws governing energy, and the derivations from special organizations of these laws which are applicable to various or specific forms and structures and to their relations with other forms and structures.

It is generally recognized by biologists that the workings of all the gross parts of living organisms are entirely due to the reactions and interactions of the finer, microscopic units—the cells—of which all gross parts are composed. Modern experimental science is bringing forward striking evidence that all the operations of these cells are the resultant of the actions and interactions of still smaller particles within the cells. Experimental science is showing also that there seems no good reason to doubt that these constituent particles, in turn, are composed of the molecules of chemistry, whose properties depend upon the nature of those molecules. The properties of the cellular particles, as a result, depend upon the nature of their molecules and manner in which they have been related or combined to make up the particles. As the molecules

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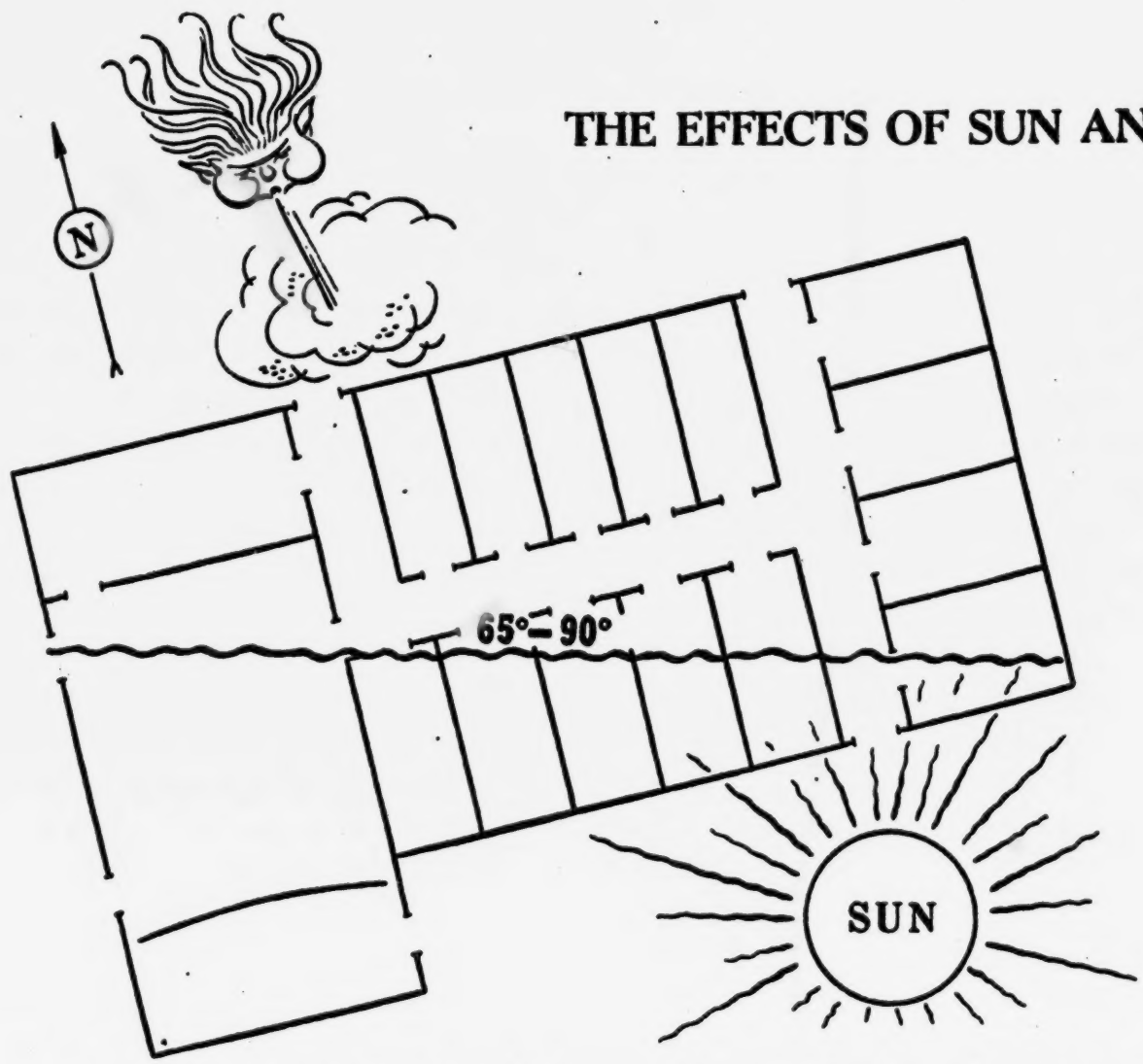
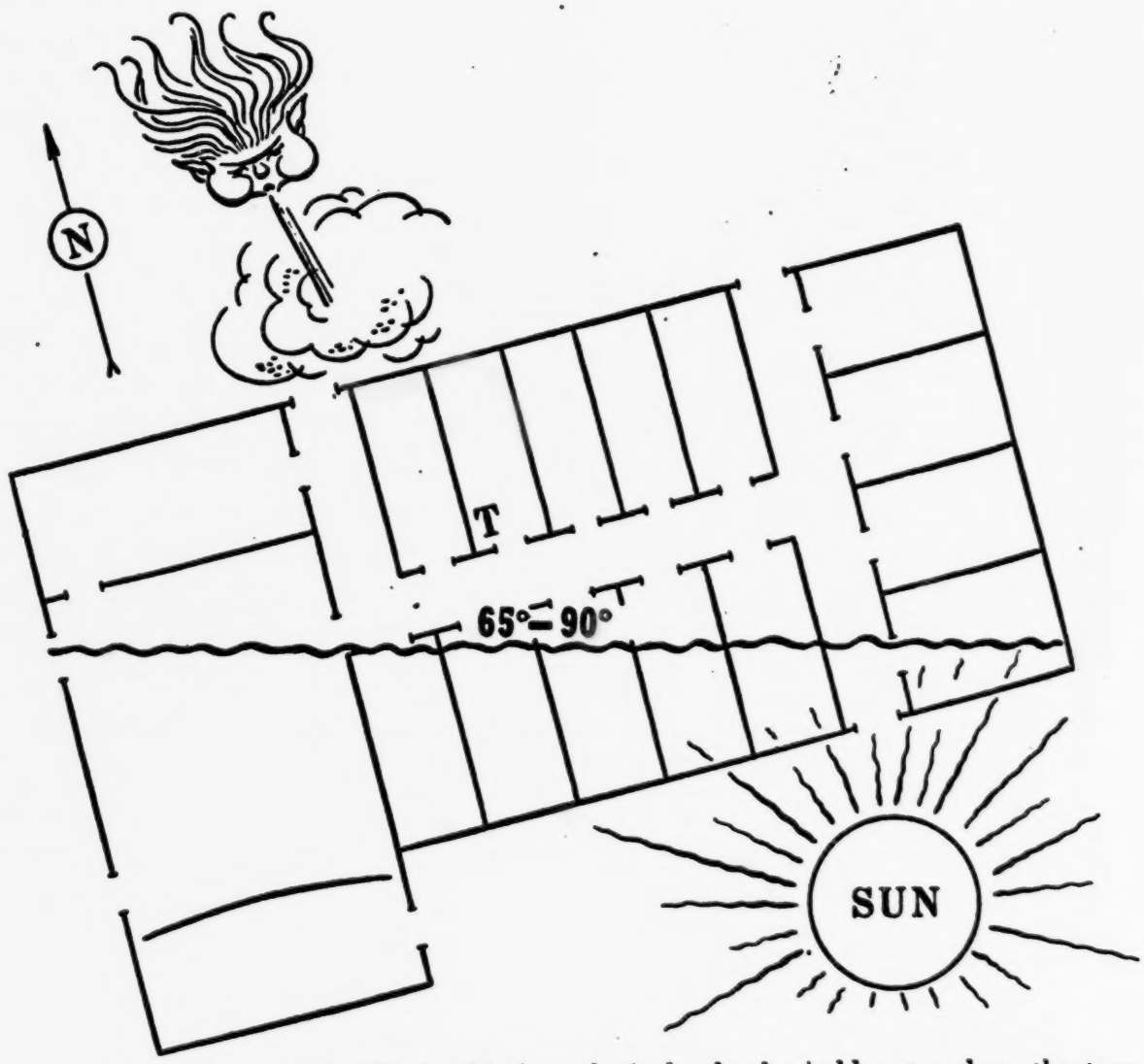
THE EFFECTS OF SUN AND WIND IN



1 Sun and wind are dynamic factors in classroom heating and ventilating. Here, in this hypothetical school, the sun and wind have created a 25-degree temperature differential. Thermal conditions in each classroom will change as the sun moves, as the wind shifts, increases or decreases.

are made up of the atoms of familiar inorganic forms, most complexly arranged, yet apparently not violating the laws of chemical combination and activity, it appears as though all living things consisted, in the last analysis, of a superlatively complicated dynamic organization of atoms, in which each individual atom is identical with similar atoms of inorganic substances and works wholly according to the same laws. In fact, it can be largely demonstrated that the capacities of irritability, metabolism, and reproduction inherent in protoplasm are but the gross expressions of the whole, produced as the atoms and molecules forming specific protoplasm function together according to the laws of physics and chemistry, in responding to the energies of each other, and the forces, and the energies of other substances, which surround the whole.

CLASSROOM



2 One control (T) in this hypothetical school would not reduce the temperature range to which students would have to adjust. If the entire school were placed under this one control, the control would have to be set at a "high" figure so that the other classrooms would have at least "average" temperature.

Like inorganic matter, the function of dynamic energy systems, represented by living cells and their various combinations, is to promote their own integrity—to *survive*. That survival is promoted by living forms through adjusting internal and external forces to hold these forces in dynamic equilibrium, and through modifying their structures from time to time, within the limits of their internal equilibria, to better meet stresses produced in them by specific environments.

The permanence of an organic form and its relative position among other organic forms seems to depend, basically, both on the simplicity of its parts and the extent and variety of combinations and uses that can be made of those parts for the benefit of the total organism in various situations of a changing environment. In addition,

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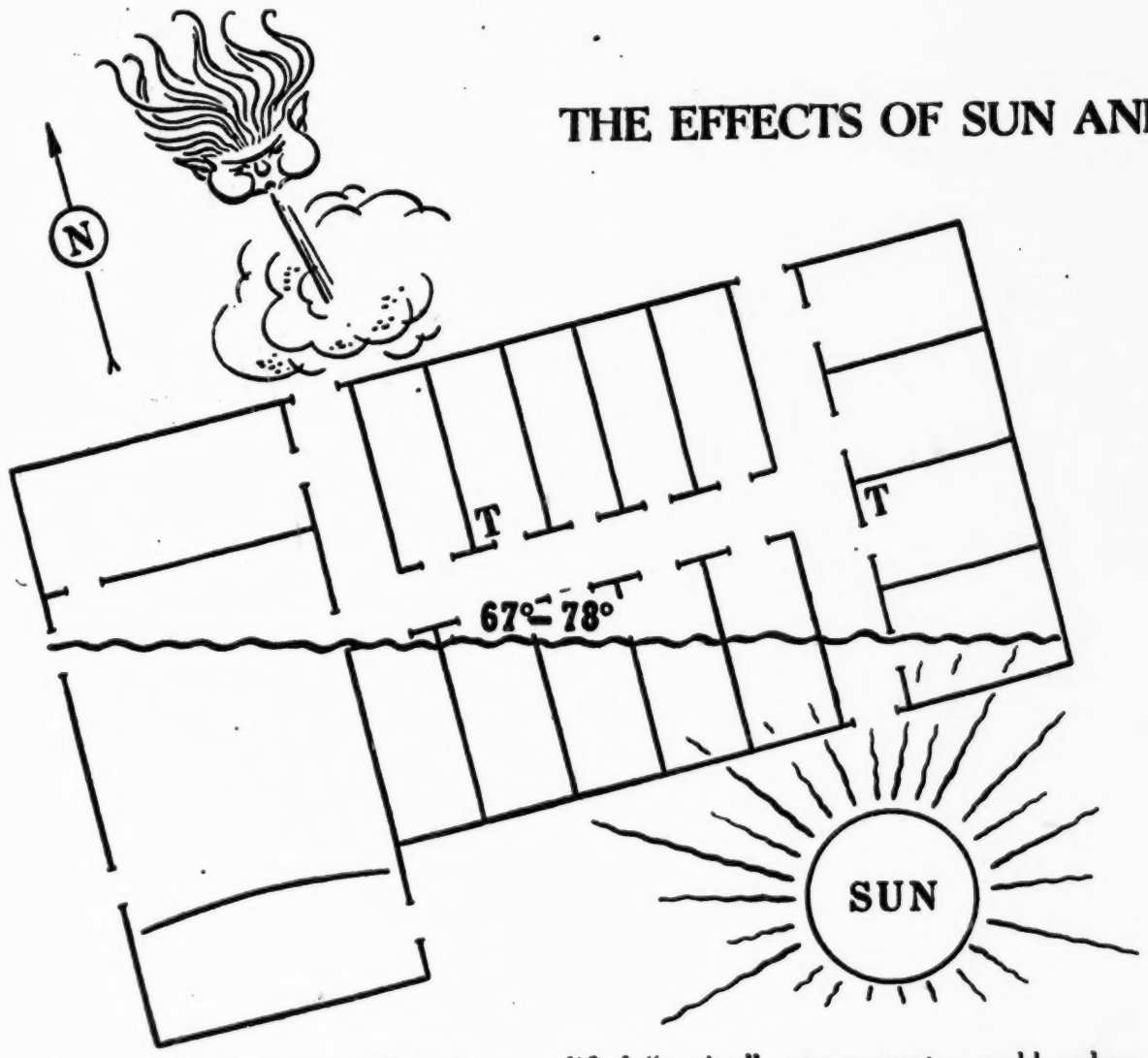
THE EFFECTS OF SUN AND WIND IN

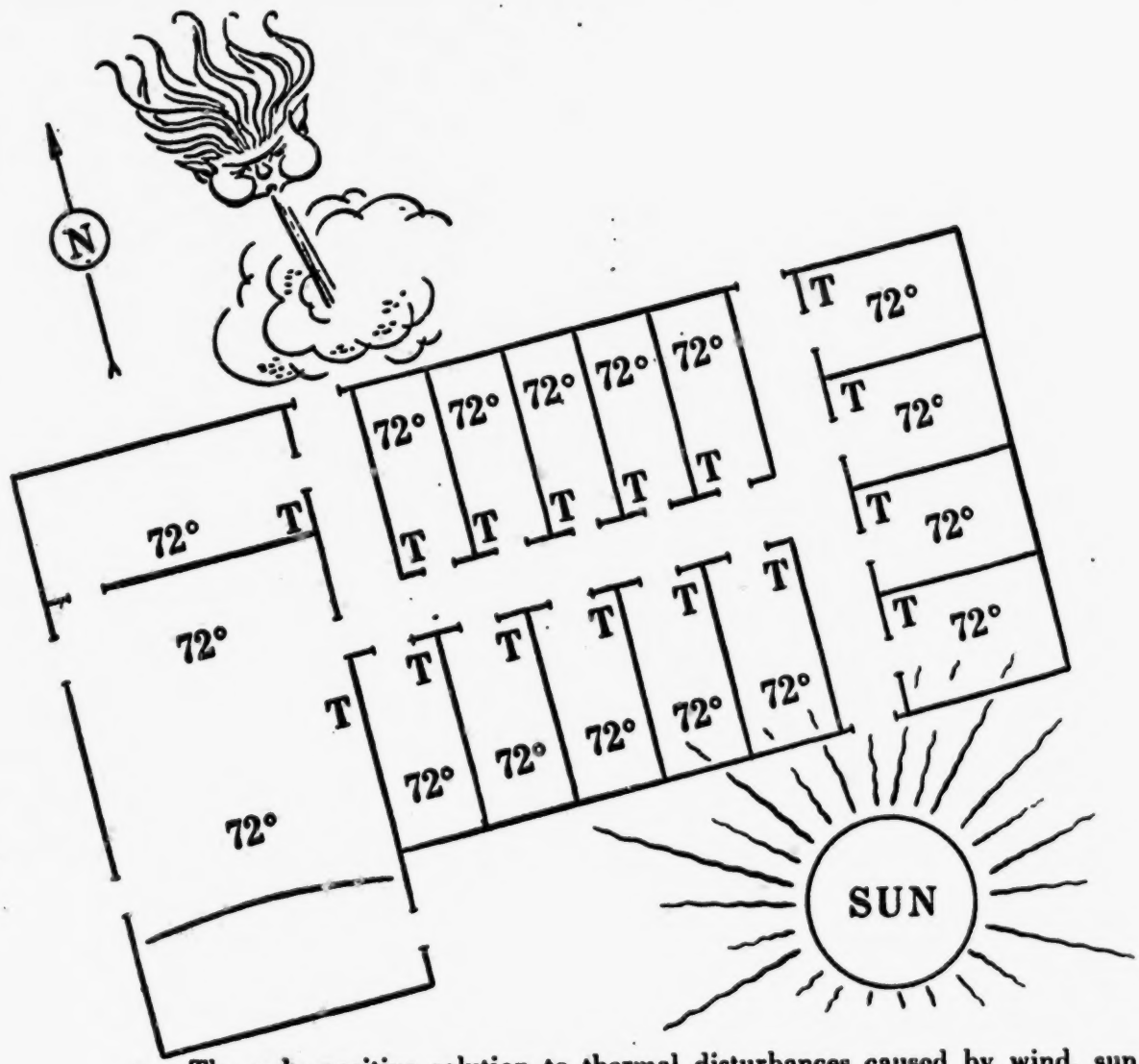


3 Two controls (T)—in a modified "zoning" arrangement—would reduce the range of temperatures in a school to about half. Temperature adjustments would still be at least 10° F. Zone systems are unable to compensate for changes which have their origin *in* the classroom, such as the size of the class or the type of class activity.

superiority in the hierarchy of development of form also rests in the organism's efficiency in organizing and equilibrating various combinations of peripheral and other structures to meet the requirements of specific situations, and the capacity of the organism's structures to undergo modification of form (cellular, systemic, or total), so as to fit better their original generalized or inherent forms or functions to the resources or energy stresses of specific environments. In other words, superiority of organic form is apparently the product of a combination of at least four adaptive mechanisms:

a. A minimum of peripheral structures which approach universality in their uses in meeting the organism's needs in its various environments;

HE CLASSROOM



4 The only positive solution to thermal disturbances caused by wind, sun and the other dynamic heat factors is a system of individual room controls. Students can move freely within the classroom, and from classroom to classroom, with a minimum of adjustment. Savings in physical and nervous energy can be applied directly in biological and growth processes or in classroom tasks.

b. A system, or systems, for the interconnection of these structures, and the other structures of the organism, which permit a maximum combination of actions of the peripheral structures while still promoting the internal equilibria of the organism;

c. Capacity to rapidly mobilize and set into and sustain action of selected combinations of structures, as needed; and,

d. Capacity for modification of various structures, as a result of function, within the limits of internal equilibria, so as to make function in relation to specific environments increasingly efficient.

Such a combination of adaptive mechanisms provides the organism with the widest possible range of potential behaviors within an efficient total structure, with all the behaviors derivable from one or more of the three physically or chemically inherent functions of protoplasm—the basic structural material of all organic forms. In this combination, modifiability of structure, in effect, records the results of the uses made by the organism of its structures in various combinations and actions, and the effect on the organism's total economy of these uses in various situations. In this way, the latitude of possible behaviors may be extended by structures having been conformed through use to meet more effectively the needs or stresses of specific situations, thus, seemingly permitting recorded experience to be drawn on in meeting subsequent similar situations.

Modification of structure through function with its apparent recording of experience is the major portion of the processes of adjustment or adaptation of higher organisms and their potential, generalized behaviors to the requirements of specific environments. In addition to modification through specific function, the peripheral structures, as well as the total organism, are modified in overall form to some extent, by the resultants of all forces in the environments in which the organism grows or functions, in order to conform to those stress-producing forces and thereby "adapt" total form so as to reduce the energies expended in resisting or responding to the factors producing those stresses.

Man owes his superior position among organic forms largely to the variability of adjustive behaviors permitted by his structures. Man's principal system for interconnecting his bodily structures, his central nervous system, is much more extensive than that of other organisms, and his structures are much more modifiable in terms of experiences. The extent of man's nervous system and his capacity for modification of structure gives man his capacity to "learn"; that is, to reorganize or change his behaviors on the basis of experience, to develop new skills through function to meet changes in his environment, and, as a result of awareness of cumulative modification through experience, to appreciate the natural and social phenomena occurring around him. Through these changes, he may select from a tremendous repertoire of possible modes of behavior those which can be effective in the manipulation of the material, the energy, and the social resources available to him at any given time. In this way,

it is possible for man to protect and promote his economy under any enormously wide range of conditions.

Man's superior position among organic forms results not only from his type of structures and the nature and extent of his interconnecting systems, but also because his periods of infancy, childhood, and adolescence are far longer than for any other organism, despite the fact that the duration of his gestation is not. Man undergoes considerable completion of structure during the period subsequent to birth, and the greatest modification of structure through function is possible only while growth and structural completion is taking place. The potential capacities of bodily structures and systems can be developed only gradually in connection with their function, and generalized structures and their behaviors can be fitted for greatest operational efficiency in specific environments only as those structures and behaviors slowly mature while in use in those environments.

Early birth in the cycles of growth, and a prolonged period of development in the environments in which the mature organism must live and survive, provides man the basis for an opportunity for efficient modification of his potentially superior structures for optimum functioning in all the environments in which man must find his satisfaction. But the very factors which provide man the basis for this opportunity threatens his chances to profit by it in a social world.

Despite man's splendid adaptability, it must not be assumed that he can ignore nature's laws and still preserve the efficiencies or the well-being of his various structures that contribute to his adaptation. The basic characteristics of organic life remain unchanged. All organisms, from the most simple to the most complex, essentially are dynamic energy systems which always maintain their basic energy equilibria within the rather narrow limits prescribed by the laws governing the interactions of the physical and chemical constituents of living matter. This must be done despite the breadth of natural or cultural changes through which the organism must go and despite the widely varying demands for the expenditures of energy imposed by the external environment. Practically all behavior and modification of structure through function can be traced ultimately to the driving necessity for keeping the biochemical and biophysical processes of the organism from varying beyond the prescribed limits. The development of special structures and organs has not freed man from the necessity for maintaining these equilibria; it merely has facilitated and given validity to the processes of protoplasmic irritability, metabolism, and reproduction by which the energy economy can be kept intact.

The human being makes effective use of the structures and capacities with which he has been endowed by nature only as those structures and capacities have been kept at optimum efficiency, and have been effectively developed and modified by function in an appropriate quantity and variety of experiences, controlled so he can form valid concepts about surrounding realities and action with which he has or may have to deal.

The first of the major functions of structures of the body—the maintenance of essential rapport with the external and internal environments of the organism—as was said earlier, has been significantly studied, and the results of these studies have been emphasized in their application to the design of man's working environments, particularly the school. This is well illustrated by the advances made in the control of light and sound, in decoration, and in the design of working equipment.

The second major function of the operation of the human organism—the provision of the energies of operation, the maintenance of readiness, and the facilitation of function—has not received equal or even adequate attention in these same schools, and yet it is of equal significance in successful learning performance, and in the ultimate well-being and efficiency of the individual.

These operations are essential to the life of the organism, and thus the energy system which we know as man can best be developed for social use by an understanding of and provisions for its total dynamic properties. The vital unity of such an organism is "identified with the functional and structural unity of its total reaction pattern."[8]

The energy system of the human organism is constantly engaged in energy interchange and energy transformation. These energy exchanges must build up the body structure at the same time that they serve the body function.

In the human organism, "structure and function are entirely interdependent, the organism forming itself structurally by function, and functioning through its form."[10]

The human organism maintains its identity only by maintaining a fairly constant structure. To do this it must make up for the disintegration which takes place as a result of reacting to the stimulation of its environment. When a factor in the environment is related to the organism's interests, it stimulates the organism to action and into an outburst of energy calculated to produce those actions which will satisfy the organism's needs.

It is essential to the life of the organism to maintain certain constant energy states, but, in using its tools in response to environmental stimulation, it is continuously losing energy in all directions.

Therefore, it must develop and maintain its own energy reserve. It must derive and store from the fuel supplies accessible to it enough energy to carry on its behaviors, as well as to take care of building and repair of reactive tissues.

These energy functions are the metabolic or biochemical activities of the body. In an average adult man, not more than 2.5 to 3 per cent of his daily food intake (chiefly protein) is used in constructive metabolism, i.e., tissue repair. In an average child this amount increases to 12.5 per cent of his total intake to provide also for growth. Only a small portion of the daily intake of both adult and child—on the average of about 5 per cent—is represented by energy leaving the body as mechanical energy, the rest being liberated as heat and expended to maintain the body temperature. In other words, the second major function in the operation of the body is largely

related to heat production and the maintenance of body temperature. The reason for this, and its significance to learning, becomes apparent when we remember that organic function is largely biochemical, and one of the basic principles in chemistry is that "the speed of reaction is a function of the temperature of reaction."

The maintenance of a relatively narrow range of body temperature is necessary to maintain the "readiness" of various systems of the body at a state where they can be called into action, and act appropriately, within the time necessary for action and in the sequence necessary for adequate and purposeful action.

Production of heat in acting is not only a product of the "work" performed in acting, but it also an expeditor of that action.

The dissipation of the excess heat produced by body actions over that necessary to maintain the body temperature at an optimum level for "readiness" to act, is a basic survival mechanism of the organism so that its integrity can be preserved and it will be in an efficient and effective state for meeting subsequent environmental demands at least expense.

The designer of working environments for the child should be fully conversant with the heat regulating mechanisms of the human organism, if he would make full provision for effective learning, full growth, and optimum development of the child in school.

5. *Body Temperature and Its Regulation**

The human body is constantly engaged in the production of heat from metabolic processes within the cells. Body temperature represents the balance struck by the heat produced in the tissues and the heat lost to the environment. Man possesses mechanisms for maintaining body temperature against changes in environmental temperature when free of sustained task demands. However, when environmental temperature factors place demands on these mechanisms, the altered psysiology alters the effective functioning of those body systems used in cultural and learning tasks.

The average temperature of most healthy people, as determined by thermometers placed in their mouths, is around the classic 98.6° F. (37.0° C.) when their temperatures are taken while they are awake and engaged in no particular activity. Their rectal temperature, at the same time, will be about a degree higher and their axillary temperature about a degree lower. Some people will show average temperatures a fraction of a degree higher or lower than 98.6° F. However, this average temperature is not a constant holding throughout the twenty-four hours of the day. A difference of 0.5°, 1.0° and even 2.0° F. occurs in most individuals between the maximum in late afternoon or evening, and the minimum about 4 or 5 o'clock in the morning. Some people, and especially night workers, show a reversal of these maximum and minimum temperatures. Body temperature will also show increases over average temperature when an individual is performing certain activities.

Average body temperature, as represented by the classic 98.6° F., probably represents an approximation of the body temperature needed for optimum physiological readiness to perform purposefully in relation to external stimulation. If so, then "readiness" to perform sustained purposeful tasks would decline as body temperature dropped below this level, or as it exceeded the upper limit of the diurnal range of body temperature.

The temperature of internal organs is higher than that of the skin. The temperature of the liver, for example, is about 100° F. whereas that of the skin covered with clothes is from 75° to 93° F. The temperature of the bare skin varies widely with environmental temperature. Temperature of covered skin will depend upon the heat-insulating properties of the clothing, air movement, humidity, and other environmental factors.

Heat production in the organism is the result of chemical reactions. The chemical changes in living cells by which heat is produced, energy is provided for the vital processes and activities, and new material is assimilated for growth and tissue repair are metabolic processes.

*With the exception of paragraph two, which is the author's own, this chapter is adapted in large part from Chapter LIV, "The Body Temperature. Heat Balance." PHYSIOLOGICAL BASIS OF MEDICAL PRACTICE, Best and Taylor, Fourth Edition, The Williams and Wilkins Company, Baltimore, 1945.

The body's metabolic aspects are dual in nature. There is the constructive aspect, called anabolism by which the body builds up, stores, and distributes its nutritive substances. And there is the destructive aspect, called catabolism, by which the body decomposes and oxidizes these substances into simpler forms with accompanying liberation of energy.

Food taken in by the body undergoes combustion in the tissues. Its energy potential is converted into other forms of energy . . . mechanical, electrical, chemical and thermal.[13] In the resting body, all the energy liberated from the food ultimately appears as heat. It is for this reason that the heat unit, the large calorie,* has been designated as the most convenient one for measuring and expressing the energy exchanges of the body.

The metabolic or basal heat production rate of the body is expressed in terms of calories . . . the number of calories per square meter of skin area per hour.

The basal metabolism is defined as the heat production of a subject as nearly as possible at complete bodily rest, some hours after food and with the room temperature at about 20° C. But muscular exercise, ingestion of food, and environmental temperature have a "powerfully stimulating effect upon metabolism,"[14] that is to say upon the body's production of heat and energy.

The human body is constantly engaged in the production of heat from metabolic processes within the cells. If its heat balance is to be maintained, it must lose a compensable amount of heat.

Body temperature represents the balance struck by the heat produced in the tissues and the heat lost to the environment. Mammals, including man, possess mechanisms for maintaining body temperature within limits of physiological tolerance against changes in environmental temperature when they are free of sustained task demands. These mechanisms, operating largely through the instigation of the autonomic nervous system, sense heat loss or heat gain in the body and set up appropriate activities or adjustments within the body to bring body temperature back to balance, or within the physiological limits of temperature needed for survival. In the case of heat loss, muscles are set into action so as to increase metabolic rate in order to produce more body heat. In case of heat gain, action is slowed down, blood is diverted to the surface of the body, sweating is started, and other mechanisms are set to work to eliminate excessive heat. In either case, the altered physiology alters the effective functioning, at least temporarily, of body mechanisms used in cultural and learning tasks.

As we have seen, heat production is the result of chemical reactions and is spoken of as the "chemical regulation of body temperature."

Heat loss is dependent upon physical and physiological factors and is called the "physical regulation of body temperature."[15]

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*Calorie or Cal.; i.e., the quantity of heat required to raise the temperature of a kilogram of water 1 degree C. from 15° to 16°.

The loss of heat from the body takes several routes . . . through the skin, through the excreta (urine and feces), and through air which is breathed out. It may be lost from the surface of the body by radiation, conduction, convection, or evaporation. There is also some heat lost by raising the air which we have breathed in to body temperature.

Under ordinary conditions over 95 per cent of the total heat loss occurs through radiation, convection, conduction, and evaporation of water from lungs and skin. The air is a very poor conductor, so conduction plays a very minor role except when the body is in contact with a cool object. Radiation is responsible for about 55 per cent of the total heat loss and convection for 15 per cent.

The total quantity of heat lost in twenty-four hours must, of course, just equal the amount produced; otherwise the body temperature would rise or fall. The heat production of an average man doing light work is about 3,000 Calories. The proportions of this which are dissipated through the various channels at ordinary room temperature are given in the following approximate figures. (From Best and Taylor):

	Calories	Per Cent
Radiation, convection and conduction	2,100	70
Evaporation from skin and lungs	810	27
Warming inspired air	60	2
Urine and feces (i.e., heat of these excreta over that of the food)	30	1
Total daily heat loss	3,000	100

The loss of heat by radiation, convection and conduction varies with air temperature, humidity, and air movement, and with the nature and amount of clothing. Rate of cooling varies with the temperature of the air and that of colder objects in contact with or near the body. When a large temperature difference exists between the body and the air and objects in contact or near by, the body loses heat rapidly through radiation, conduction and convection. The rate of heat loss, however, becoming gradually less as the temperature of the environment approaches that of the body.

As has been pointed out, conduction plays a very small part in the loss of body heat. At ordinary room temperatures only 2 to 3 per cent of the total heat loss can be accounted for through conduction.

Convection (the rate of movement of warm air from the neighborhood of a heated object) varies, of course, with the temperature of the atmosphere. The clothed body has a layer of warm moist air in contact with the skin which tends to become trapped. In the absence of a temperature difference between it and the external air, or in the absence of some air movement to cause mixing, this warm air will remain practically stagnant. However, when the atmosphere is cooler, convection currents are set up which mix the air lying against the skin with fresh air. Convection is essentially

dependent upon the relative densities of airs at different temperatures, the warmer and lighter air rising, the cooler air falling. Probably the most important factor influencing heat loss by convection is air movement. A breeze or wind greatly increases heat loss by convection up to a velocity of around 6,160 feet per minute. A rise in wind velocity above this has little further effect.

More than half the total heat loss is brought about through radiation. The human skin is an almost perfect "black body radiator." It radiates nearly all infrared rays or absorbs to the same extent all rays which fall upon it. The main factor influencing heat loss through radiation is the temperature of surrounding objects relative to that of the skin. The body, for example, radiates heat to a block of ice but absorbs heat from a hot stove or radiator. It should be remembered that the air intervening between the body and the source of heat is not heated by radiant energy, but only by convection. Another factor, though a very minor one, is the humidity of the atmosphere. Air with a high water vapor content is more opaque to radiant heat than dry air. Heat lost through radiation is therefore slightly reduced when the relative humidity is high.

The nearer the temperature of the environment comes to that of the blood the smaller will be the amount of heat which can be lost by radiation and convection. At an air temperature of about 98.6°F. heat loss by these means must cease. At higher air temperatures than this, the body, were no other means of cooling available, would actually gain heat. Through the secretion and evaporation of sweat and the exhalation of water vapor (expired air is practically saturated with moisture) large quantities of heat are lost to the body. Even at ordinary room temperatures when there is no obvious perspiration the heat lost through evaporation from the lungs and skin amounts to from 22 to 27 per cent of the total heat loss. At higher temperatures the heat lost by evaporation of water increases in proportion to that lost by radiation and convection. Evaporation plays little part in heat regulation until the air temperature reaches between 82.5° and 86°F., the heat loss by this means remaining nearly constant below this level but increasing rapidly above it. Visible sweating in a person at rest generally starts at air temperatures between 80° and 90°F., and at a temperature above 95°F. evaporation accounts for all or nearly all the heat lost from the body.

Evaporation from the body surface occurs quite independently of sweat secretion, however, for the skin is not entirely impervious to water; fluid extravasated from the cutaneous capillaries seeps into the epidermis. It has been shown for persons in whom sweat glands were absent from birth that some 18 grams of water per square meter of body surface may be lost hourly by evaporation. This is about the same as that of a normal man under ordinary conditions, and represents a total daily heat loss of about 450 Calories for a body of average size.

The rate of the evaporation of water is influenced inversely by the degree to which the atmosphere is already saturated with moisture, i.e., by its relative humidity. Sweat which is not evaporated but simply drips from the skin, of course does not

increase heat loss. For this reason the sweating mechanism for the elimination of heat is badly crippled when the relative humidity is high. We are all familiar with the fact that one feels hotter and suffers more discomfort when the atmosphere is hot, and humid ("muggy" or "sticky") than when it is simply hot and dry. Evaporation, and consequently heat loss by this means, is greatly hastened by air movement. The layer of air nearly saturated with water vapor lying next the skin is thus replaced by drier air.

While biochemical and temperature functions are the same, structural differences between adults and children make for differences of thermal requirements. The school designer not only should know the operation of the heat regulating mechanisms of the human organism in general, but also should know the differences of expression of those mechanisms between children and adults.

6. *Thermal Differences Between Children and Adults*

The incompleteness of growth and development of the school child, differences of metabolic rate, and the mass-skin-area ratio of that child as compared to the adult, necessitate a different set of standards for controlling the thermal environment of the school child than those used for controlling the work environment of the adult.

Though the human organism starts out as a single cell and preserves a general identity throughout its life, its more specific structure and function patterns are developed or constituted as the organism grows and develops. The process of growth produces progressive changes in structure and closely-correlated changes in function. The child is structurally and experientially naive.

Gesell calls our attention to the fact that the child is not a "little adult" but an "immature and growing organism." The child at birth is incomplete in both the size and structure of all of his bodily systems. The state of completeness he will eventually attain in these systems is determined by two processes—growth and development. These processes, to a considerable degree, also determine the systemic and total efficiencies—physiological and psychological—he will eventually reach.

The processes of growth and development are far too complex to wrap up their definitions and descriptions into neat little packets. Nevertheless, some working concepts on growth and development are necessary for our purposes here. Our first problem is one of definition. The terms "growth" and "development" are used with a slight difference of meaning in medical literature than given them in most of the literature concerning learning processes, although both uses of these terms are derived from the same concepts.

Kugelmass* presents a good summary of the medical use of these terms when he says: "the processes of growth are two-fold—developmental and anabolic. Developmental changes involve proliferation or division and increase in the number of cells; differentiation or specialization of structure and organization or segregation according to structural and functional properties. All true growth, normal, abnormal or pathologic, is the resultant of these three fundamental processes characterized by specific chemical reactions. These are distinct from the processes involving anabolism or increase in size, weight or mass for incorporation of new material into that already present is not an essential accompaniment of developmental processes per se. Developmental functions produce an increase in the number of cells, or division of their substance, and bring about structural and functional specialization into effective aggregates. Although development may take place without increase in size, weight or mass,

*I. Newton Kugelmass, THE NEWER NUTRITION IN PEDIATRIC PRACTICE, J. B. Lippincott Company, Philadelphia, 1940.

growth toward the complete and maturely functioning organism is dependent upon processes of anabolism. Growth is thus the expression of the combined action of the developmental process of proliferation, differentiation and organization and the metabolic processes of anabolism. . . . Growth continues until the production of a certain number of cell units is complete although the basis for this finite number is not vested in the inherent power of growth."

"Growth . . . is most intense before the master activities of gland, muscle, and nerve are established. As growth proceeds to its limit, activities of gland, muscle and nerve become possible. The impulse to grow ceases while these activities continue throughout life. . . . Growth is self-regulatory. It keeps with some variation within well-defined limits. . . . Cells grow actively until a particular organ reaches a certain size and completes a definite inherited pattern. . . . Then growth-regulating factors assume control with the result that growth processes in the cells are reduced to a minimum sufficient only to repair incidental wear and tear."

For our purposes here, *growth* is the term used to designate the processes of completion of a certain portion of the size and structure of the bodily systems through biochemical activity that has been biochemically initiated by virtue of the incompleteness of those structures. In other words, molecular, cellular, and systemic incompleteness creates a biochemical instability which incites biochemical activity towards completion that persists until stability is approximated. The upper limits of growth are determined by, (1) inheritance, (2) nutrition, (3) disease or trauma, (4) previously attained growth, (5) in any system, by the growth of other bodily systems, and (6) "development," not only as that term is used by Kugelmass, above, as part of the growth function, but also as it is used below in respect to adaptation and learning.

The child grows as a whole, but he does not grow synchronously with respect to all his varied parts and systems. He may be lagging in one field and accelerated in another. Growth follows certain innate patterns determined by the initial structural material of the organism (the fertilized ovum) and by systemic and intersystemic imbalances; and, each pattern has a relative upper limit in time.

In addition to the processes of proliferation, differentiation, and organization mentioned above, from the learning point of view, *development* also involves the modification of growth by the activities and experiences through which the organism goes. In other words, it is the adaptation that the organism makes to specific requirements of its environment while growth is taking place. In these adaptations, the generalized systemic forms and functions laid down by the innate patterns of growth are modified, or converted into specific forms and patterns determined by environmental requirements.

Development in the above sense as contrasted to growth, is principally a biophysically initiated process although it involves biochemical activity after initiation. Development is limited by (1) the inherent capacity of the organism to perform, (2) environmental limits, (3) previous experiences, (4) the state of the total organism

at the time of any experience (i.e., a. its organization, b. disease or trauma, c. growth achievement), and (5) nutrition.

From birth to maturity, the child, from a dynamic point of view, is a totality which is constantly undergoing alteration to maintain an integration of parts which are in many and various stages of completeness in their own growth and development. The slightest distortion of any of these parts deforms or limits the growth and development of the whole.

The full development of the child's potentialities can come only through use or function. This functioning, however, must wait upon organic, psychic, and experiential readiness. It must be appropriate to the biologic purpose of the organs, bodily systems, and capacities activated, and it must have relationship to the needs and purposes of the organism as a whole.

Growth produces progressive changes in structure with accompanying and closely correlated changes in function. At various times in growth, certain structures or combinations of structures reach points in completion where it is possible for the organism to react to stimulation in ways in which it could not react previously. These various points in growth are designated *maturities*, and they determine certain generalized responses, or possibilities for performance. They do not, however, determine specific social behavior. For example, a child will respond to stimuli leading to standing and walking when neural, skeletal, and muscular growths attain the proper maturity. However, these maturities will not lead the child to walk purposefully to some place. To walk purposefully to some place, the child must learn—through experience or activity—the advantages to him of walking to that place, and his structure must be modified through this activity to permit him to walk to that place so that the end gained will have greater value than the energy, or effort, put forth. Learning is largely a biophysically initiated biochemical change which leads to specific efficiencies in adaptation. Development includes this learning plus the modification of the total physiology or function involved in any specific performance as adaptation simplifies the actions required by that performance.

The maturation process takes time. Merely exposing the child to his total culture will not impose that culture upon him by any simple process of absorption. The acquisition of that culture can be achieved by the child only through the slow patterning of his reactive mechanisms, the gradual integration of his functions, the gradual accrual and perfection of mature and efficient structure.

The child is directed toward his highest maturation potential by lawful growth forces which are construed by the child's biological and biochemical heritage into orderly sequences. But laws of growth, like other laws, are effective only to the extent that they are implemented through enforcement. Tensions, stresses imposed by energy organizations, and restraints hostile to the organism's growth and development determinants may impede, inhibit, or dissipate these growth forces.

Because of the nature of the processes of growth and development, and the

differences between children and adults, designers of the thermal environment for school children must not and cannot use adult standards for this environment in prescribing for the thermal needs of children.

The heat-regulating mechanisms of the organism are not fully developed at birth. The body temperature of the newborn child tends to be irregular and unstable. The metabolic rate is high in children and diminishes gradually with maturity. The rate of heat production per square meter of body surface grows less, progressively, from infancy to old age.

Kugelmass[19] best summed up the metabolic needs of the school child when he said:

> "The child needs food for *growth, maintenance,* and *repair* of his body. . . . Each of these processes takes place simultaneously. . . . Protoplasm is self-perpetuating, capable of amassing living substance at the expense of non-living matter which serves as food; it is self-regulating, capable of utilizing indispensable nutrients for maintenance; it is self-reparative, capable of replacing, through the agency of food, the structural increments degraded by metabolic processes. These chemical changes involve the liberation of potential energy of foodstuffs in the form of mechanical work, heat, or electricity; and the disintegration of complex compounds into simple substances which cannot be used further by protoplasm and are therefore excreted. Thus does the stream of matter into protoplasm continue to produce growth if synthetic processes in the cells remain in excess of energy-yielding reactions and to maintain life if constructive processes are counterbalanced by destructive."

The child's readiness to learn and to perform at any level of his education, and his ultimate degree of maturity and performance efficiency is dependent upon maintaining his growth rate at an optimum. This is well borne out by the researches in child development of Gesell, Olson, and many others. This aspect of the child's development is critical at all age levels to maturity.

What must be recognized by the designers of the thermal environment of the child is that the human organism has no special mechanism to assure that the metabolic needs of growth will be met. *Activity demands for nutrients always take precedence over growth needs in the child.*

In our consideration of the growth processes of the child and the subtle but accumulative effect of environmental factors upon those processes, we must remember that these processes are of a dual nature. There are the changes in the growing organism, which involve division and increase in the number of cells; "differentiation or specialization of structure; and organization or segregation according to structural or functional properties." These are not to be confused with the processes contributing to increase in size, weight, or mass. If the first takes place without increase in the size, weight, and mass of the organism, the child is not approaching the complete and maturely-functioning organism with optimum progress.

The average daily caloric requirement to meet growth needs during the ages of 6 to 16 years is 10 to 15 calories per kilogram of body weight. Growth function is a storage function and no heat is produced in this process. The encroachment of this function by anabolic demands due to stress or excessive action induced by environmental factors can do nothing but handicap ultimate successful learning and the final, complete, and mature functioning of the organism . . . which also are dependent upon the same processes of anabolism.

Two other factors of growth are worthy of recognition.

"Heat production in the body bears a definite relation to the amount of oxygen consumed and the amount of carbon dioxide eliminated. The metabolic rate or energy production in the body can be calculated if we know either the amount of oxygen consumed or the amount of carbon dioxide exhaled during a given period."

Measurements of the oxygen consumption of the maturing organism at various stages of its development have indicated that oxygen consumption in the child is increased during periods of rapid growth. These perirods are both age-related and seasonal. Growth is greatest during the sixth year and between the twelfth and sixteenth years of the child's life. In addition, the basal metabolic rate of all children is maximal between November and January, as this period is also the time-span of the greatest increase in height and least gain in weight during the year. This increase in oxygen consumption during growth spurts necessitates a more careful control of the thermal environment of the child so as to protect growth than is needed for the control of the environment of the adult whose maximum growth has already been attained.

A second factor worthy of recognition in our appraisal of the mechanistic and functional variations in the growing child is that, in the developing child, and especially the young child, incomplete nervous structure means muscle tone is poor, so loss of body heat is not well-regulated without adequate protection by careful control of the thermal environment.

The muscular tissues (particularly of the extremities) and the liver, wherein numerous chemical reactions are carried out, are the main sources of the body's heat.[20] The rise in metabolism which results from a fall in atmospheric temperature is effected through an increase in tone of the skeletal muscles and in some instances by fine involuntary contractions, shivering or chattering of the teeth. All these activities contribute to the body's efforts to restore temperature balance. In experiments where the skeletal muscles are paralyzed or where the muscles have been isolated from control, the body loses its powers of chemical regulation of body temperature and its ability to sustain a normal body temperature against excessive heat loss.

A child comes into his increasing powers primarily through intrinsic growth forces which change the inmost architecture of his nervous system.[21] The muscle tonus of the child is determined more by the innate maturation of the nervous system than by experience.[22] Therefore, in the immature organism the architecture of the nervous system is still in the formative stage and muscle tonus is poor. The neuro-muscular

"thermostat" does not "trip" properly and the warning system of the organism against external temperature threat works imperfectly.

Thus in young children the mechanism for controlling the loss of heat is poorly developed and hence their body temperature is more likely to undergo variations. A child, for example, may develop a fever by a fit of crying. Strong emotion may raise metabolism. 5 to 10 per cent above basal level.

Basal metabolism is more closely related to surface area than to height and weight. Under basal conditions energy is continually produced to maintain the normal body temperature by compensating for the loss of heat from the surface of the body.

The surface area of the child is greater in proportion to his mass than is that of the adult, and since the child can only dissipate the same amount of heat per unit of body *surface*, he must obviously generate more heat per unit of body *weight*. This variation occurs between the child and the adult, and, in lesser extreme, between a child of small size and a larger child.

Since the heat is produced in the tissues (the muscles, liver, etc.), these tissues and the organs which they make up must be the seat of a much more active metabolism in the child.

If the volume and weight of the adult body is three times that of the child, but its surface area is only twice that of the child, then the metabolism of the adult would be, not three times, but only twice as great as that of the child.

In general, the basal heat of the adult is 20 calories per square meter of skin surface per hour. In children the heat is as follows (from Kugelmass):

Age	Boys	Girls
	(cal./sq. meter/hour)	
7 years	47.5	46.5
13 years	41.9	34.7

The heat production per minute of the average resting child in a fasting state is about 1.22 calories.

Research in children's nutrition shows the total daily caloric requirements of the school child of all ages, as compared to the adult, to average as follows (Kugelmass):

Requirements per Kilogram of Body Weight

	School Child (cal/kg)	Adult (cal/kg)
Basal	35	25
Growth	10	0
Activity	25	10
Food Conversion	10	5
	80	40

The basal requirements given above include the 2.5—3 per cent of the daily

intake needed for tissue repair. This amount, together with the requirements for growth, include the non-activity and non-heat producing aspects of the child's daily intake. With the exception of the approximately 5 per cent of the caloric intake which is converted into mechanical energy in activity in both the child and the adult, the remaining items of basal need, activity, and food conversion shown above for both children and adults represents the heat production of each per day.

The total daily caloric intake of the child in school is virtually the same as that of the adult engaged in a sedentary occupation. To illustrate: the average daily requirement of a man (150 lb.) engaged in sedentary work, is 2,400 calories. The average daily needs of the school child are as follows (Kugelmass):

Children's Total Daily Caloric Requirements

Age	*Boys*	*Girls*
7 years	1,918	1,757
9 years	2,287	1,932
11 years	2,406	2,096
13 years	2,522	2,381
15 years	3,068	2,337

In a thermal environment regulated for adults not only is the child more subject to erratic chemical body temperature control because of the immaturity and imperfection of his regulatory mechanisms, but, by virtue of his proportionately smaller mass surface area, he is denied the opportunity to lose a compensable amount of heat through skin surface channels, that is to say, through radiation, convection-conduction, and evaporation.

In addition, since the school child's caloric intake is approximately the same as the adult, and his metabolic rate or rate of heat production greater, his diminished heat loss through body surface areas enhances his problems of maintaining his body temperature at its optimum level and further underlines the importance of control needs and processes in the thermal environment of his classroom.

Because of these differences between children and adults, adults cannot be depended upon to regulate classroom temperatures or other thermal factors solely in terms of their own subjective judgment of the "warmth" or "comfort" of the room. The possible error in such adult judgments becomes more obvious when we consider age and sex differences in the thermal responses of adults.

The "Heating, Ventilating, Air Conditioning Guide, 1952," of the American Society of Heating and Ventilating Engineers reports: "On the whole, women of all age groups studied prefer an effective temperature for comfort 1.0° higher than men. All men and women over 40 years of age prefer a temperature 1° ET higher than that desired by persons below this age." We must constantly bear in mind that in public schools most teachers are women, most janitors are men, and, there is a considerable number of both who have passed the forty-year mark.

If efficiency of the preforming child is to be one of our major criteria for evaluating the thermal environment, then, the classroom designer must not only be conversant with body heat regulating mechanisms, but also must be familiar with body heat output in the different activities of the school child.

The incompleteness of growth and development of the school child, differences of metabolic rate, and the mass-skin-area ratio of that child as compared to the adult, necessitate a different set of standards for controlling the thermal environment of the school child than those used for controlling the work environment of the adult.

7. *Body Temperature and Activity*

Because the child "learns through activity" and that activity is physical even though covert in an apparently passive learning situation, and, because organic structure and function are modified through stress and action induced by any energy organization, the thermal environment of the school child requires more careful control in all of its aspects (temperature, air movement, and humidity) and more careful planning for programming these controls, than what is presently done if we would assure promotion of optimum learning and development.

Today's curriculum, as has already been pointed out, is an activity curriculum, and activity means heat production over and above basal needs. Not only must the thermal factors of the child's classroom environment be controlled so that growth and development will be protected by preventing undue heat loss (and, controlled at standards other than those for adults), but, provision must also be made for controlling the child's thermal environment in a manner that the heat of activity can be dissipated so that optimum body temperature of readiness to perform may be maintained.

Freeman's studies of the energetics of human behavior, McCulloch's work in applying cybernetics to the human nervous system, Renshaw's work in visual dynamics, and the work of many other reputable investigators in the psycho-physical aspects of learning and behavior have all demonstrated that perception, learning, and other psychological phenomena are derived from motor actions, covert and overt. These studies have been further reinforcing the educators' knowledge that the child "learns through activity." In other words, there is a physical aspect . . . a heat producing aspect . . . in every part of the learning process as directed by the school. How significant this aspect is becomes apparent when we examine some existing data on caloric needs in the child while engaged in different activities. For example, the caloric consumption of the child . . . his heat production . . . increases 3 per cent over basal needs while merely solving a mathematical problem. Emotional responses (which enter into the attitudinal aspects of learning) can increase heat production 10 per cent over basal production and just the motor activity of sitting at a desk increases heat production by 25 to 50 per cent over resting production of heat.

Other data on the heat production changes in psycho-motor function shows increased energy expenditure, over basal, in problem-solving situations changing metabolic rates by as much as 100 to 200 per cent in talking or walking, and from 5 to 10 times in some types of severe activity.

Some of these changes for the child of school age are illustrated in the following table (Kugelmass):

Activity	Requirements in cal/hr/kg
Sleeping	0.93
Lying still	1.10
Sitting at rest	1.43
Reading aloud	1.50
Standing relaxed	1.50
Standing at attention	1.63
Light exercise	2.43
Walking slowly	2.86
Active exercise	4.14
Walking downstairs	5.20
Walking upstairs	15.80

We are realizing more and more that if all conscious ideas and events have motor accompaniments, we can enhance a learning experience and enrich it by utilizing those motor or activity accompaniments to best advantage. Education's knowledge of the activity aspects in learning is bringing about a sweeping curricular modification over the methodology of the three "R's" of a generation ago. Instructional methods are becoming more informal and less "informational."

Classrooms are becoming workrooms, and disciplined inactivity is changing to activity which is varied and directed throughout the day. Physical action follows listening and bookwork. Communication with other children, co-operative research, creative dramatic play, action, and construction are being integrated into a vital and dynamic learning climate that is replacing individual passive study of books.

Control of the thermal environment of the classroom is becoming something much more than merely the provision of enough heat to keep the children "warm," or enough opening for air changes to provide basal oxygen needs or to control odor. Heat gain as well as heat loss must be considered. Control of heat, air movement, and humidity must be taken into account to promote optimum purposeful behavior in learning, and to maintain optimum body temperature for readiness to perform in all of the days activities.

All the curricular changes and our newer insight into the functioning of the organic child mean that rigid, objective supervision, but flexible control of all the factors of the thermal environment are necessary in our classrooms.

Data and opportunity for both these approaches to control are possible. Measurements of the metabolic shift in children, over basal activity, have been made in sufficient numbers, and exist in standard pediatric literature. Also, curricular programming is following closer and closer the basic diurnal metabolic cycle of children, which is also well established. What remains is the conversion of these physiological data into engineering applications.

Because the child "learns through activity" and that activity is physical even though covert in an apparently passive learning situation, and, because organic structure and function are modified through stress and action induced by any energy organization, the thermal environment of the school child requires more careful control in all of its aspects (temperature, air movement, and humidity) and more careful planning for programming these controls, than what is presently done if we would assure promotion of optimum learning and development.

8. *Body Temperature and Problem-Solving Rapport*

Full rapport in problem-solving situations (such as school tasks) is dependent upon shifts in internal body temperature and upon close maintenance of certain internal body temperature levels. This necessitates rigid control of all the thermal factors of the classroom to maintain these internal body temperature levels, within the varying rates of heat production in all the various activities of the child in order to assure optimum rapport with the learning task and optimum learning and developmental outcome.

There is, as we have seen earlier in this discussion, a point of thermal neutrality at which the organism, fasting and at rest, has to take no particular action to maintain its heat balance. The reactive processes within the organism go on, but only at a low level.

If through a change in the organism's thermal environment, heat loss is increased, the organism goes immediately to work to counteract this heat loss.

It moves into a "Zone of Vaso-Motor Regulation"[16] against cold, in an effort to protect the temperature of the deep tissues by a decreased flow of blood through the skin. If this reaction is inadequate, the body takes further steps, increasing heat production by increasing muscular tension, by shivering, by a spontaneous increase in activity. In short, it moves into a "Zone of Metabolic Regulation" against excessive heat loss.

Should these precautions be inadequate, the body enters a "Zone of Inevitable Body Cooling."

Thus we see that the human organism attempts to preserve its deep body temperature against cold external conditions by a fall in the temperature of the peripheral tissues, brought about by the decrease in heat-transmitting blood flow to those surface tissues, and, when further activated, by an increased expenditure of energy.

Should the thermal environment undergo a change in the direction of greater heat, or should body heat production go above a rate necessary to maintain optimum body temperature, the body moves one by one into the other graduations of thermal regulation. First is the "Zone of Vaso-Motor Regulation" against heat, in which the blood-flow to the skin is stepped-up, to carry heat to the outer tissues and raise the temperature of the skin surface, so heat may be lost to the environment. Where the threat persists, it then enters the "Zone of Evaporative Regulation" against body heat. Should these measures fail, it will then be forced into the "Zone of Inevitable Body Heating."

Within this thermal range, certainly between the two extremes of life-threat to the organism, and within the fluctuation beyond which the organism must concentrate its forces of regulation against serious, though not fatal, threats to its equi-

librium, there lies a narrow range in which the organism is in comparative balance with its thermal environment.

Beyond the upper level of thermal heat within this range, the body would lose systemic integration. The signal system would alert the mechanism's regulatory processes against further heat production, saying, in effect, "If you permit the body temperature to go up much farther, you will destroy the mechanism. Stop performing and lose heat."

Beyond the lower level of this narrow range, the body also loses capacity to utilize its various systems constructively, so the signal device once again alerts the regulatory processes, saying, "The body has gone far enough in using energy. Shut down activity so it can clean out the by-products of action or store up new energy for other activities."

This range, as has been said, seems to be between approximately body temperatures of 97° and 99°F., with the mean at about 98.6° F. The widespread assumption, to repeat for emphasis, that the temperature of the human organism is normally maintained, neatly and precisely, at the 98.6° F. indicated by the red line on the ordinary clinical thermometer is fallacious. Although, as we have shown, the regulative mechanisms of the human body keep its internal temperature fairly constant, this internal temperature can and does, under normal conditions, fluctuate within a range, as shown by mouth temperatures, of one or two degrees around the mean.

In his studies of the sleep-wakefulness cycle,[17] Kleitman, professor of physiology at the University of Chicago Medical School, has demonstrated that this range exists, and, further, that it varies through the diurnal cycle. In experiments with sleep deprivation, Kleitman and his associates found that disabling effects of prolonged wakefulness fluctuate in a daily cycle, with the experimental subject reaching his lowest ebb during the early hours of the morning, roughly from 2 to 6 a.m. They further discovered that these daily ups and downs in the ability to ramain awake run parallel to fluctuations in the body temperature.

As has been pointed out in this discussion, the basic protoplasmic activities in the human organism are chemical in nature. A characteristic of chemical reactions is the chemical fact[18] that an increase in temperature increases the velocity of a chemical reaction. In other words, life processes increase their speed with increasing temperature.

Our bodily activities, being chemical in essence, are speeded up by a rise in temperature and slowed down by its fall, as Kleitman points out.

As Kleitman has demonstrated, man's bodily temperature regularly goes up and down each day on a fairly smooth, wavelike curve, with a peak or plateau in the middle of the waking period and a minimum at night during sleep. Diurnal temperature variations have been verified by the findings of other authorities.

Kleitman likens sleep and wakefulness to water in a frozen and liquid state, respectively. It is as easy to recognize frank sleep states and frank wakefulness states

as it is to recognize the two extreme states of water. In between and revealed only by more clinical measurement are gradations of wakefulness and sleepiness, just as there are gradations between frozen and liquid states in water.

To carry his analogy further, Kleitmen draws a parallel between the increasing agitation of molecules as water temperature rises and increasing alertness attendant upon a rise in body temperature. This correlation between temperature peaks and heightened alertness, and between temperature valleys and declining alertness, is indicated in our everyday expressions pertaining to human behavior, which we frequently frame in temperature terms: cold reception, warm greeting, feverish activity, boiling mad.

The uniqueness in Kleitman's research is his demonstration that problem-solving rapport goes up as the internal temperature goes up above the average, but within the diurnal difference range. The converse is also true. Rapport with the environment and the ability to solve problems also goes down as internal body temperature drops below accepted averages. These changes of internal body temperature are mediated by a control mechanism inherent in the nervous structure of the organism and by the stimulation of muscular action with its resultant increase in heat production.

These changes of environmental rapport with their accompanying changes of problem-solving capacity are apparently related to changes in the velocity of chemical reaction within the motor system of the organism due to the increases or decreases of body temperature. These controlled shifts of as little as a fraction of a degree over the average of internal temperature apparently alters this velocity sufficiently to bring the speed of reaction up to a level at which the whole resources of the organism are integrated into an action pattern which makes for solving environmental problems with least effort. Similar reductions in internal temperature apparently introduce inertias, due to a slowing of reaction time, that put the organism into a basal or resting state, thereby reducing or severing rapport with the external surround.

Excesses of internal body heat, over the optimum temperature level for problem-solving situations, seems to trigger a control mechanism which reduces the organism's activity or integration, just as losses of internal heat below the optimum lower level for rest trigger motor action to increase the heat level.

We find then, in our study of the human organism and its general characteristics, that somewhere within its diurnal temperature difference range there is an optimum point at which the organism is at greatest problem-solving rapport with its environment.

With the wide variation in heat production of the child in various curricular activities, and the above need for maintaining internal temperature at a critical level in order to have optimum problem-solving capacity, the whole problem of control of the thermal environment must be approached, not as a matter of comfort, but as a matter of the needed retained heat for best learning.

Considerably more work must be done to establish the norms of these upper and

lower temperature levels for children, together with their tolerances for variations while engaged in school activities. Sufficient information of temperature changes in various school activities now exists . . . as well as information on the limits within which these norms will probably fall . . . to necessitate school controls being planned with all the aspects of the thermal environment in mind which could affect this temperature function in learning in all types of learning tasks. In addition, emphasis must be put on the need for complete, rather than partial controls of the thermal environment of classrooms, including flexibility of these controls, in order to assure that the child has command over all his capacities and resources while performing school tasks.

The classroom must be regarded, not simply as a shelter, but as an educational tool which helps the child realize all the potentialities for growth and development with which he came into the world.

With this in mind, a third principle of thermal control of the classroom can be stated:

Full rapport in problem-solving situation (such as school tasks) is dependent upon shifts in internal body temperature and upon close maintenance of certain internal body temperature levels. This necessitates rigid control of all the thermal factors of the classroom to maintain these internal body temperature levels, within the varying rates of heat production in all the various activities of the child in order to assure optimum rapport with the learning task and optimum learning and development outcome.

9. *Some Conclusions*

Our survey of the characteristics of the human organism in general, and those of the learning child in particular, has shown us that three factors must be taken into account in the design and control of the thermal environment of classrooms:

1. The child is different from the adult;
2. Thermally-induced stresses can alter the growth, development, and learning of children; and
3. The child's problem-solving capacity is affected by the effective temperature of his classroom.

We have also seen that classrooms are not merely containers in which children, during their school hours, are kept "safe," and "warm," and "comfortable." Classrooms are significant parts of the organic child's educational experiences. Classrooms provide those organizations of energies that instigate the generalized organic behaviors which purposeful education directs into those experiences making for fully-developed, healthy, satisfying and satisfied, efficient members of society.

We have seen, further, that one of the major functions in the operation of the human organism—the provision of the energies of operation, the maintenance of organic readiness to perform, and, the facilitation of operation of body systems—is effected by the organization of the thermal environment. The successful realization of this function of the learning child in modern curricula cannot be reached by provision and control of heat sources alone. The maintenance of essential body temperatures for adequate learning performance is dependent upon all the factors that make for effective control of the learning child's thermal environment. The control of any of the factors in the thermal surround cannot be left to chance alone. Classrooms must be designed to provide optimum *effective temperatures* for the school child in his educational milieu through direct or indirect control of all the factors of the thermal environment affecting the organism, including heat, humidity, and air movement.

While the effective-temperature scale of the American Society of Heating and Ventilating Engineers may be entirely satisfactory for adult environments* . . . and no question is raised here as to such a use of that scale . . . a number of factors inherent in the nature of the child and the learning process preclude the unqualified acceptance of that scale as a standard for classrooms. This does not necessarily mean a sweeping rejection of all the quantitative values established by that scale. However, the nature of the child and the critical place the school now plays in his growth, development, and well-being, and in his ultimate success and efficiency, call for a

*The American Society of Heating and Ventilating Engineers in 1949 reported that the optimum Effective Temperature for men and women at rest and normally clothed in winter is 66° ET with a range of from 63° to 71°, and, in the summer 71° ET with a range of 66° to 75°.

broader emphasis on all the factors of the thermal environment which must be controlled, together with a further determination of additional quantitative values and the equating of all quantitative values with the requirements of the curriculum.

Considerable research is still needed to establish resting and performance norms of effective temperature for children in school. There is urgent need for undertaking this research. In the meantime, because of the organic differences between children and adults, it should be constantly borne in mind that effective temperatures for children performing in school are obviously lower than those for adults (probably one or two degrees lower) and controls for the significant factors in the classroom environment should be provided and adjusted to take into account this difference. Those adults in charge of the classroom should be taught not to adjust these controls in terms of their own subjective judgment or reactions to the temperature of the room, but, to make these adjustments in terms of the successful performance and reactions of the children in the room. Adults in the classroom should make other provisions (such as adequate clothing) for meeting the needs of their own body temperatures.

Because of the current tremendous need for added classrooms, a great many classrooms will be designed and built before effective temperature norms are established for children in school. Most of these rooms will be designed for informal or activity programs—as they should be. If we do not want these rooms to defeat the very purpose for which they are built—or, to become obsolescent before they are erected—then their design must take into account the significance of the thermal environment for learning children, and provision must be made in their structuring for controlling all the factors which make for effective temperatures within ranges significant to the performing organic child. The extent of these ranges can be computed or anticipated from data at hand in existing pediatric and educational literature, even though precise norms are not available.

Advances in one area of design of classrooms, due to extensive available information in that area, should not be carried to extremes at the expense of other needs of children in school. For instance, increase of openings in classrooms to admit more needed daylight should not be carried to an extent that the thermal environment suffers. In fact, in all energy areas designers should derive classroom solutions by means of what Caudill and Reed have so aptly called the "simultaneous approach to the design of classrooms,"* in the discussion of which they say, "any studies relative to classroom design must be based on an understanding of the total function of the classroom. Only through such an understanding can the area of studies be oriented properly."

If our schools would meet the needs of our children in growing and developing into effective and efficient adults, then this understanding so necessary for proper

*William W. Caudill and Bob H. Reed, "Geometry of Classrooms as Related to Natural Lighting and Natural Ventilation," Research Report No. 36, Texas Engineering Experiment Station, July, 1952.

orientation in classroom design studies must include an understanding of the control of heat, air movement, and humidity, which are of such vital significance to learning children, along with an understanding of the control of light, sound, structural materials, space for teaching, and the other areas that enter into making adequate classrooms in schools of today and tomorrow.

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Data used in this study have been taken from the bibliography listed. The hypotheses, applications and conclusions contained herein are the writer's, and he, alone, should be held responsible for their validity.

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